

# New species of freshwater diatoms from acidic localities along the Atlantic Coastal Plain of the United States

Peter A. Siver, Paul B. Hamilton, and Jeffery Pelczar

**Abstract:** During our investigations of freshwater sites along the Atlantic Coastal Plain of North America we had the opportunity to critically study five interesting diatoms with light (LM) and scanning electron microscopy (SEM), each of which is described here as a new species. Two of the organisms are in the genus *Eunotia*, *Eunotia lewisii* Siver & Hamilton sp. nov. and *Eunotia quadra* Siver & Hamilton sp. nov.; two in *Frustulia*, *Frustulia crispula* Siver, Pelczar, & Hamilton sp. nov. and *Frustulia inculta* Siver, Pelczar, & Hamilton sp. nov.; and the last is *Neidium trainori* Siver & Hamilton sp. nov. All five species are reported from acidic, poorly buffered, dilute waterbodies high in dissolved humic substances. Two of the taxa are found in suites of waterbodies in close geographic proximity, two in somewhat disjunct regions, and the fifth is only known from the type locality. The relationships of each taxon to similar species are discussed.

**Key words:** Atlantic Coastal Plain, Bladen Lakes State Park, Croatan National Forest, diatom, *Eunotia*, *Frustulia*, Pocosin National Wildlife Refuge, *Neidium*, new species, Pinelands National Reserve.

**Résumé :** Au cours de leurs recherches sur des sites d'eau douce le long de la Plaine côtière de l'Atlantique en Amérique du Nord, les auteurs ont eu l'opportunité d'étudier de façon critique cinq diatomées intéressantes, à l'aide de la microscopie photonique (LM) et électronique par balayage (SEM), et ils décrivent chacune d'elle comme une nouvelle espèce. Deux de ces entités appartiennent au genre *Eunotia*, *Eunotia lewisii* Siver & Hamilton sp. nov. et *Eunotia quadra* Siver & Hamilton sp. nov., deux au genre *Frustulia*, *Frustulia crispula* Siver, Pelczar & Hamilton sp. nov. et *Frustulia inculta* Siver, Pelczar & Hamilton sp. nov., et la dernière est nommée *Neidium trainori* Siver & Hamilton sp. nov. Les cinq espèces se retrouvent toutes dans des plages d'eau, diluée, acide, faiblement tamponnée, avec de fortes teneurs en acides humiques. On retrouve deux de ces taxons dans des plages d'eau géographiquement voisines, deux dans des régions relativement disjointes et on a trouvé la cinquième seulement sur le site ayant fourni le type. Les auteurs discutent des ressemblances de chacun des taxons avec des espèces de même apparence.

**Mots-clés :** Plaine côtière de l'Atlantique, Refuge national de la faune de Pocosin, *Neidium*, nouvelle espèce, « Pinelands National Reserve ».

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## Introduction

A primary goal of our research program is to document and inventory diatoms and scaled chrysophytes in ponds and lakes along the eastern coast of North America. To date, we have analyzed collections from over 300 waterbodies from Florida to Newfoundland from which we have described over 30 new taxa, including the diatom genus *Brevilinea* (Siver et al. 2008) and new species in the diatom genera *Brachysira* (e.g., Shayler and Siver 2004), *Eunotia* (Siver et al. 2006), *Frustulia* (Siver and Baskette 2004), *Neidium* (Siver et al. 2003), *Nupela* (Siver et al. 2007), and *Stenopterobia* (Siver and Camfield 2007). In addition, we have proposed six new combinations and emended numer-

ous other descriptions based on observations using scanning electron microscopy (SEM) (Hamilton et al. 2004; Hamilton and Jahn 2005; Siver and Hamilton 2005; Siver et al. 2005). Most of the new taxa were described from localities with a low pH, reflecting the acidic preferences of many of these genera (Siver et al. 2004, 2005).

Our more recent efforts have focused on waterbodies situated on the Atlantic Coastal Plain, including ones in the Bladen Lakes State Forest, Croatan National Forest, and the Pocosin National Wildlife Refuge along coastal North Carolina, and within the Pinelands National Reserve in southern New Jersey. The majority of sites along coastal North Carolina are very acidic, poorly buffered, humic stained, and associated with pocosin or Carolina bay vegetation (Richardson et al. 1981). In addition, most of the waterbodies were situated within Carolina bay depressions, a vast network of shallow, elliptical basins with a northwest-southeast orientation found scattered over the Atlantic Coastal Plain from Florida to New Jersey, with a concentration in North Carolina (Ingram and Otte 1981; Ross 1987). Practically all of our North Carolina sites had a pH below 5, many below pH 4, and were significantly stained with humic compounds yielding Secchi disk depths less than 0.5 m (Lott and Siver 2005).

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The Pinelands National Reserve represents a  $1.1 \times 10^6$  acre (1 acre = 0.40 hectares) mosaic of forests, wetlands, ponds, streams, and farms situated on the outer Atlantic Coastal Plain in southern New Jersey (Zampella et al. 2001). The Pinelands lie atop the Cohansey Aquifer, which delivers acidic and nutrient-poor water to the lakes, small ponds, wetlands, and streams (Zampella et al. 2001). Humic substances from the surrounding sandy soils result in elevated concentrations of colored dissolved organic matter, and most ponds have a pH between 4.0 and 5.0. It is of interest that the Pinelands represent the northern or southern distributional limit or transitional zone for numerous terrestrial plants. Although we have documented many genera along the Atlantic Coastal Plain, the flora in our study sites is largely dominated by species within the genera *Eunotia* and *Frustulia*, with lesser contributions from *Pinnularia*, *Aulacoseira*, *Neidium*, *Nupela*, *Brachysira*, *Kobayasiella*, and *Stenopterobia*. A complete description of the flora will be forthcoming. Aerial photographs, on-site images, and chemical conditions at the time of collection for all sites can be found at [silicasecchidisk.conncoll.edu](http://silicasecchidisk.conncoll.edu).

Diatoms are found in virtually all aquatic habitats and often comprise a significant portion of the biomass of primary producers. Numerous species can grow and proliferate under very specific chemical and physical conditions, such as low pH, high nutrient concentrations, or low dissolved salt levels. As a result, diatoms can serve as powerful bioindicators of environmental conditions and have been especially valuable in determining anthropogenic effects of such stressors as eutrophication and acidic deposition on waterbodies (Stoermer and Smol 1999). Since the siliceous and taxonomically diagnostic remains of diatoms become archived in sediments, these organisms are routinely used to reconstruct past environments (Camburn and Charles 2000). The success of the use of diatoms as bioindicators, however, demands accurate identification at or below the species level.

The purpose of this contribution is to formally describe five new species within the genera *Eunotia*, *Frustulia*, and *Neidium*. Four of the species representing the genera *Eunotia* and *Frustulia* were found in suites of waterbodies in specific geographic regions, while the *Neidium* taxon has only been observed in the type locality. Since each of these genera is cosmopolitan and especially common in acidic waterbodies, delineation of these new species will aid future paleolimnological investigations.

## Materials and methods

Surface sediments and attached periphytic samples were collected from 41 waterbodies, including 7 from the Bladen Lakes State Forest, 9 from the Croatan National Forest, 12 from the Pocosin National Wildlife Refuge, and 13 from the the Pinelands National Reserve. A sediment core from the center of each waterbody was retrieved with a Glew gravity corer (Glew 1989), sectioned on-site with a Glew extruder (Glew 1988), and the top 1 cm portion examined for diatoms. Aliquots of multiple periphyton samples from a given locality were mixed and prepared for diatom analyses. Approximately 0.5 g of surface sediment or mixed periphyton from each lake was oxidized with a mixture of sulfuric

acid and potassium dichromate and cleaned according to Marsicano and Siver (1993). Aliquots of each resulting clean slurry were air dried onto pieces of heavy duty aluminum foil and glass coverslips. The aluminum foil samples were trimmed, attached to aluminum stubs with Apiezon<sup>®</sup> wax, coated with a mixture of gold and palladium for 1 min with a Polaron Model E sputter coater, and observed with a Leo 982 field emission SEM. The cover slips were mounted onto glass slides with Naphrax<sup>®</sup> and observed with a Leica DMR microscope. Light micrographs were taken with a Sony DKC-ST5 digital camera. All digital images used for this paper were cropped and assembled into finished photographic plates with Adobe Photoshop.

The Secchi disk depth and geographic coordinates were taken with a 20 cm black and white disk and a Trimble Geoplotter GPS unit, respectively. Chemical analyses of samples from each waterbody followed the procedures of Ahrens and Siver (2000). Briefly, pH and conductivity were measured on the same day of collection with a Fisher Acument 640-A pH meter and a Hydrolab DataSonde 4A, respectively. Total phosphorus was determined using the stannous chloride-ammonium molybdate colorimetric assay after a persulfate digestion (APHA 1985). For total nitrogen, samples were first digested using the alkaline persulfate oxidation method (D'Elia et al. 1977) and then analyzed using the *N*-(1-naphthyl)-ethylenediamine dihydrochloride method (United States Environmental Protection Agency 1983, Method 353.2). Water color was determined by the platinum-cobalt method (APHA 1985).

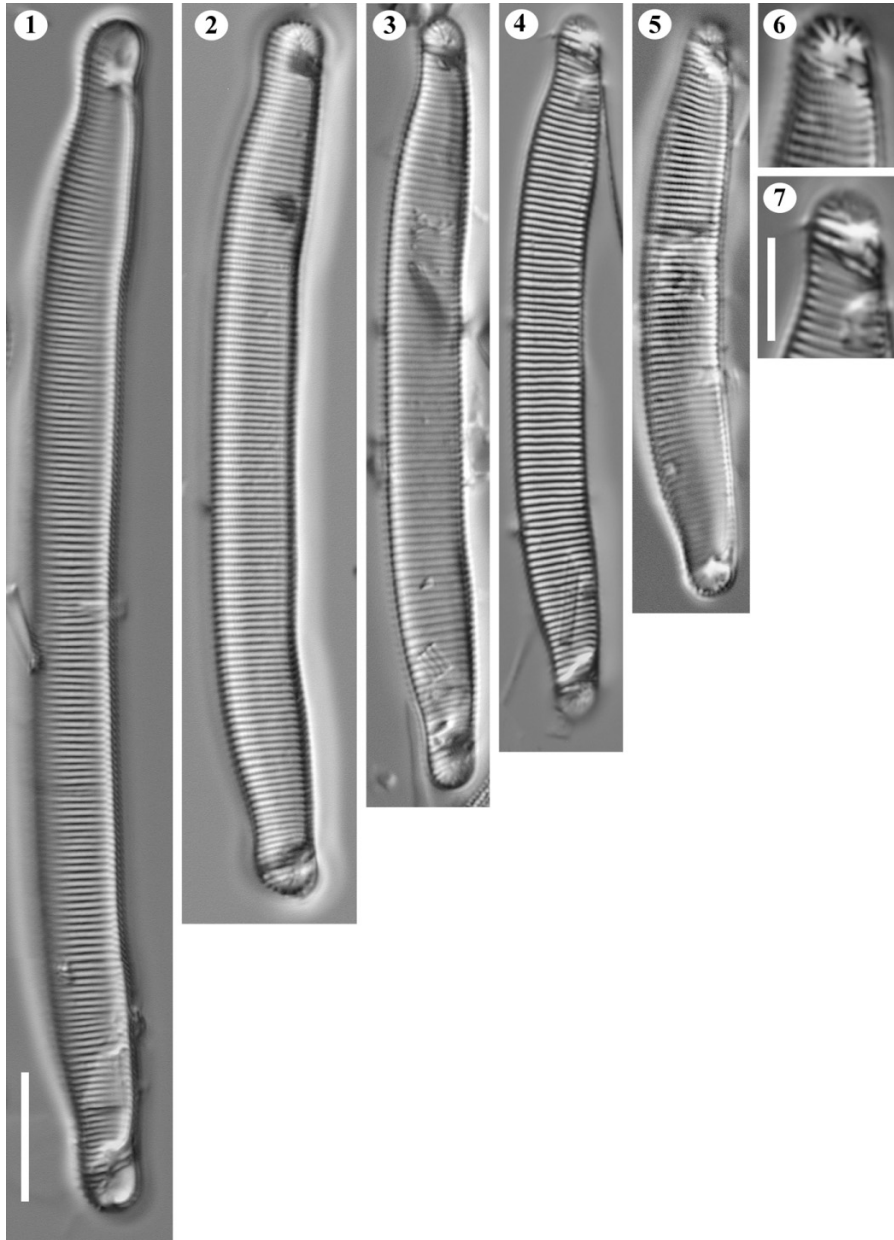
Subsamples of clean slurries from all study sites have been deposited at the California Academy of Sciences (CAS) and the Canadian Museum of Nature (CANM). Holotype and isotype glass slides for each new species described in this paper were also deposited at national museums as noted below. A minimum of 25 valves for each taxon were measured to attain morphometric data. Length and width measurements were made with either light microscopy (LM) or SEM, while all striae densities were estimated using SEM.

## Observations and discussion

### *Eunotia lewisii* Siver & Hamilton sp. nov. (Figs. 1–13)

DESCRIPTION: *Valvae dorsiventrals, elongatae, propagala lati rotundi leviter rostrati apices* (Figs. 1–5). *Ventralis margo rectus, parallelus cum dorsali margine, tum extendit extrinsecus ubi raphe incipit et apex constringit secus dorsalem marginem. Extensio plus conspicua in longis valvis. Ventralis valva margo incrassatus, saepe formans parvam continuam porcam* (Figs. 8–10). *Series parvarum spinarum super costas secus dorsalem marginem* (Fig. 11), *interdum deminutarum vel absentium. Striae aequaliter dispositae, parallelae, densior ad apicem et radiatae ex terminali hyalina area ad limbum* (Figs. 8–10 and 12). *Areolae parvae, circulares, densae, inobterunt in externis et internis paginis* (Figs. 8–13). *Proximalis raphe terminat in medio deorsum limbum; raphe recta, parallela ad margines curvat super frondem circum 3 μm ex apice* (Figs. 8–10). *Distalis raphe fissura, parvus porus positus circum 1/4 trans frondem* (Fig. 8). *Raphe saepe interrumpit porcam in ventrali margine* (Fig. 8). *Interna frons juxta distalem raphem extremum,*

**Figs. 1–7.** Light micrographs of *Eunotia lewisii*, including a size reduction series (Figs. 1–5) and close-ups of the apex containing the thickened siliceous band with the distal end of the raphe extending slightly onto the valve face (Figs. 6–7). Scale bars = 10  $\mu\text{m}$  (Figs. 1–5) and 5  $\mu\text{m}$  (Figs. 6 and 7).



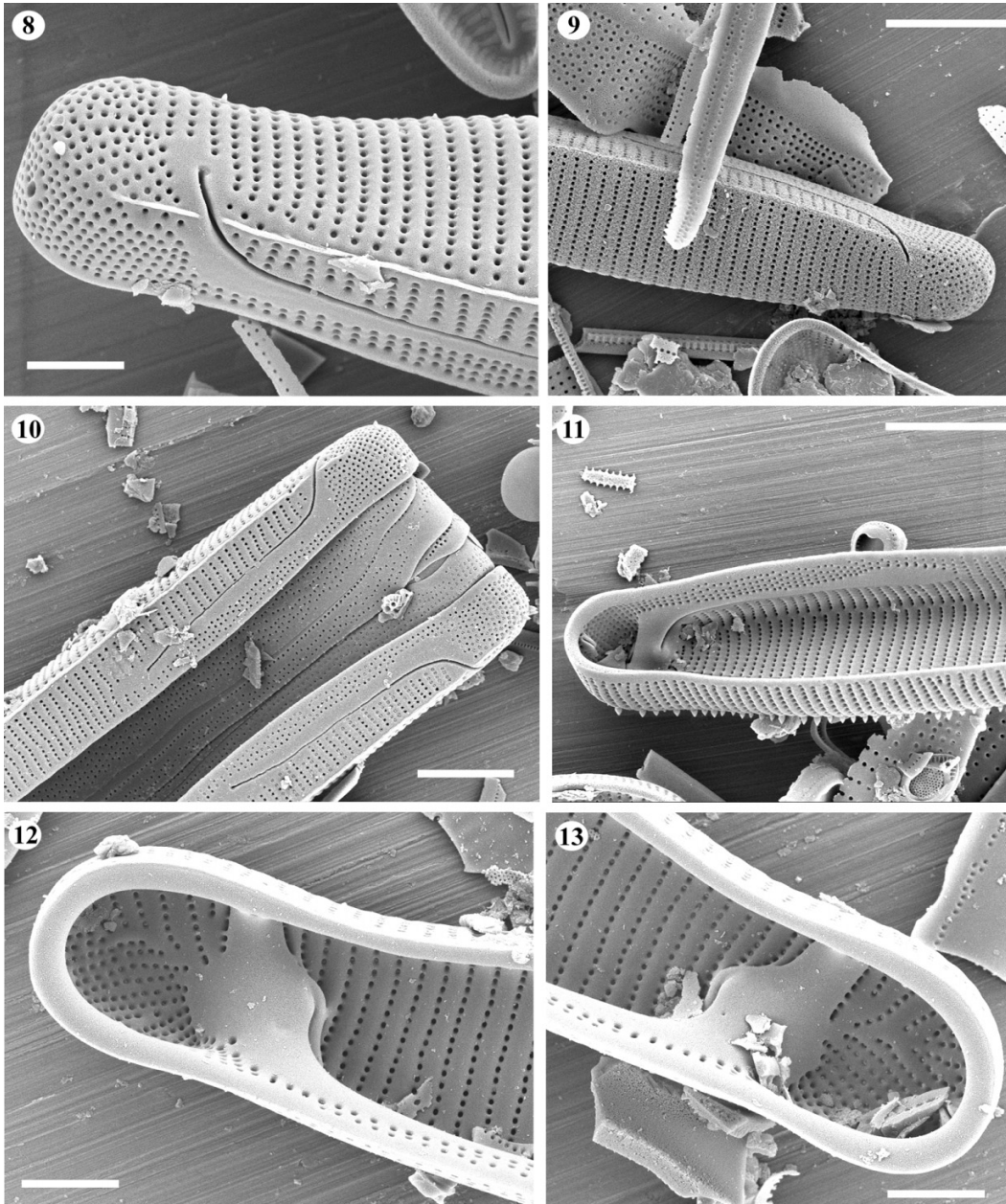
*crassa hyalina area extendit ex ventrali limbo et terminat approximatum vel ad dorsalem marginem* (Figs. 6, 7, and 11–13). *Distalis raphe extrema curvat super proximalem laterem incrassatae structurae; parva tumida helictoglossa adest in medio trans frondem* (Figs. 12 and 13). *Inferius limbus margo incrassatus, apprime ad apicem* (Figs. 12 and 13). *Bene evoluta rimoportula, parallela cum apicali axe adest prope limbum basem ad apicem* (Figs. 11 and 13). *Valvae 44–112  $\mu\text{m}$  longitudo, 5.5–6.5  $\mu\text{m}$  latitudo, striae 20–25/10  $\mu\text{m}$ .*

Valves are dorsi-ventral, elongate, with offset broadly rounded and slightly rostrate apices (Figs. 1–5). The ventral margin is straight and parallel with the dorsal margin over most of the valve, then extends outward slightly at the point

where the raphe begins and where the apices start to constrict along the dorsal margin. The extended section is more noticeable on longer valves. The ventral valve margin is thickened, often forming a small continuous ridge (Figs. 8–10). A row of small spines can be found on the costae along the dorsal margin (Fig. 11), but these can be reduced or even absent on some specimens. The striae are evenly spaced and parallel over most of the valve; at the apices the striae are denser and radiate away from the terminal hyaline area onto the mantle (Figs. 8–10 and 12). Areolae are small, circular, closely spaced and not occluded on either the external nor internal surfaces (Figs. 8–13). The proximal end of the raphe commences about midway down the mantle, runs relatively straight and parallel to both margins, then curves



**Figs. 8–13.** Scanning electron micrographs of *Eumotia lewisii*. Note the position of the raphe, the extensive number of striae surrounding the apex and the ridge along the ventral margin (Figs. 8–10), the thickened siliceous band with helictoglossa spanning the valve face along the internal surface (Figs. 11–13), the rimoportula (Figs. 11 and 13, the spines along the dorsal margin (Fig. 11), and details of the cingulum (Fig. 10). Scale bars = 2  $\mu\text{m}$  (Figs. 8, 12, and 13) and 5  $\mu\text{m}$  (Figs. 9–11).



up onto the valve face about 3  $\mu\text{m}$  from the apex (Figs. 8–10). The distal raphe fissure terminates as a small pore about 1/4 the way across the valve face (Fig. 8). The raphe often interrupts the ridge on the ventral margin (Fig. 8). Internally where the distal end of the raphe terminates, a large, solid, thickening extends from the ventral mantle, across the valve face and terminates close to or at the dorsal margin (Figs. 6, 7, and 11–13). The thickening is usually smooth and hyaline. The distal end of the raphe curves up onto the proximal side of the thickened structure and terminates midway across the valve face as a small swollen helictoglossa (Figs. 12–13). The lower margin of the mantle is thickened, especially around the apices (Figs. 12 and 13). A single well-developed

rimoportula, positioned parallel with the apical axis, is present near the base of the mantle at the very apex (Figs. 11 and 13). Valves ranged in size from 44–112  $\mu\text{m}$  long  $\times$  5.5–6.5  $\mu\text{m}$  wide with a striae density of 20–25/10  $\mu\text{m}$ .

**HOLOTYPE:** Here designated as the circled specimen on microscope slide marked “B” CAS 222073, deposited at the CAS, San Francisco, California, and illustrated in Figs. 4 and 7 (close up).

**ISOTYPES:** Here designated as the circled specimens on microscope slide marked “C” CANA 80500 deposited at CANA, Ottawa, Ontario, and illustrated in Fig. 3, and on microscope

slide marked “A” in P.A. Siver’s personal collection and illustrated in Figs. 5 and 6.

TYPE MATERIAL: Cleaned surface sediment deposited at CAS (CAS 627355) and the CANA, Ottawa, Canada (CANA 78268). Collectors: P.A. Siver & P.B. Hamilton, May 24, 2004.

TYPE LOCALITY: Chatsworth Lake, Pinelands National Reserve, Town of Chatsworth, New Jersey, USA. 39°48′55″N, 74°32′45″W.

ETYMOLOGY: The specific epithet is in honor of F.W. Lewis, a physician, early diatomist, and member of the Academy of Natural Sciences of Philadelphia.

DISCUSSION: The most obvious character that easily separates this species from all others within the genus is the internal thickened hyaline structure on which the distal raphe fissure terminates, a feature readily observed with LM to extend across the valve face. To our knowledge, the only other species of *Eunotia* with a similar structure is *Eunotia lenis* Metzeltin & Lange-Bertalot, a taxon described from Guyana, South America (Metzeltin and Lange-Bertalot 1998, Plate 63: Fig. 4). The thickened structure on *E. lenis* is not as extensive as the one on *E. lewisii*, and the valve morphologies of these two taxa differ considerably. Similar internally thickened structures are also formed on the foot poles of some species of *Actinella* (Metzeltin and Lange-Bertalot 2007). For example, *Actinella falcifera* (Metzeltin & Lange-Bertalot) Metzeltin & Lange-Bertalot forms a thickened ridge that spans the valve around the apex of the foot pole.

Spines and marginal ridges were consistently found on the valves of *E. lewisii* on the dorsal and ventral margins, respectively. Despite the fixed positions of the ventral ridge and dorsal spines, the development of these structures varied within a given population. We found specimens with well-developed ridges, well-developed spines, or both structures. In the same population, specimens with less-developed features or lacking them altogether could also be observed. Other species of *Eunotia* have spines and (or) ridges that are taxonomically diagnostic, but the distributional pattern differs from *E. lewisii*. For example, *Eunotia denticula* (Brébisson) Rabenhorst has dorsal spines, but lacks a ventral ridge (Werum and Lange-Bertalot 2004, Plate 2: Figs. 1–8; Metzeltin and Lange-Bertalot 2007, Plate 84: Figs. 13–14). Spines may also encircle the entire valve margin, for example, *Eunotia rabenhorstiana* var. *elongata* (Patrick) Metzeltin & Lange-Bertalot (Metzeltin and Lange-Bertalot 2007, Plate 82: Fig. 14) and other taxa formerly in the genus *Desmogonium*, but sometimes they are restricted to the apices. Some species, such as *Eunotia monodontiforma* Lange-Bertalot & Nörpel-Schempp (Rumrich et al. 2000, Plate 21, Figs. 5–7) and *Eunotia flexuosa* (Brébisson) Kützing (Werum and Lange-Bertalot 2004, Plate 5: Figs. 19 and 21) have marginal ridges along the dorsal margin, while other species have ridges along both margins (Siver et al. 2006; *Eunotia quadra* sp. nov., presented below). The positions of spines and ridges on most *Eunotia* species appears to be a stable character; however, based on our observations their presence or absence on a particular specimen can vary.

We first encountered *E. lewisii* while examining material from Saco Pond, New Hampshire, the type locality for sev-

eral species of *Stenopterobia* and the genus *Actinella* originally described by F.W. Lewis in 1864 (Siver and Camfield 2007). We next observed numerous specimens of this species in 9 of the 13 waterbodies examined in the Pinelands of New Jersey (Table 1). These waterbodies are all shallow, acidic, dilute, and highly humic-stained. To date, we have not observed this taxon in any other region along the Atlantic Coastal Plain, nor in New England with the exception of Saco Pond. We find it interesting that even though Lewis (1864, 1865) did not report specimens with this valve morphology from any of the localities he examined in the White Mountains of New Hampshire (including Saco Pond), we found this taxon to be abundant in the upper portions of a sediment core from Saco Pond and an important component of the current flora of this acidic waterbody. It is also of interest that in their extensive study of diatoms from numerous acidic localities in the northeastern US that Camburn et al. (Camburn et al. 1984–1986) and Camburn and Charles (2000) did not find *E. lewisii*. Given the fact that the broad hyaline region of this species is readily seen with LM, we find it hard to imagine that this species would have been overlooked by these workers and conclude that, indeed, this species is not widely distributed in the northeastern US.

#### *Eunotia quadra* Siver & Hamilton sp. nov. (Figs. 14–28)

DESCRIPTION: *Valvae longuae, lunatae, paralleli margines, latior prope apicem. Apex obtusus, quadratiformis* (Figs. 14–22). *Dorsalis margo incrassatus; tenuis continua silicea costa parallela ventralem marginem* (Fig. 23). *Striae aequaliter dispositae parallelae; ad apicem striae densior et leniter radiatae super limbum. Striae continuae trans frondem; prope polos interruptos ad parva hyalina regione approximata ad ventralem marginem* (Figs. 17–22). *Areolae parvae, circulares, arte parallelae obturunt externe ad solido disciformi hymenio* (Figs. 24–26); *interne inobterunt* (Figs. 27 and 28). *Raphe 8–10 μm longitudo, ad limbum/frondem marginem; helictoglossa ad apicem* (Figs. 27 and 28). *Externa pagina, distalis raphe fissure flectit 90° super frondem ad apicem; raphe terminat in medio secus valvam in parvo circulari poro* (Figs. 17–22 and 23–26). *Inferius margo incrassatus* (Figs. 27 and 28). *Uterque valva cum rimoportula super limbum, parallela cum apicali axe, approximata ad dorsalem marginem* (Figs. 27 and 28). *Cingulum 3–5 apertas taenias; in parte exteriori unaequaeque taeniae cum brevibus seriebus areolae. Valvae 131–178 μm longitudo, 6–7 μm latitudo, striae 11–16/10 μm.*

Valves are long, lunate, of even width over most of the valve length, becoming slightly wider near the ends and terminating with blunt, square-shaped apices (Figs. 14–22). The dorsal margin is thickened and a thin continuous siliceous ridge aligns the ventral margin (Fig. 23). Striae are evenly spaced and parallel over most of the valve, becoming slightly denser and weakly radiating away from the terminal hyaline area onto the apex mantle. The striae are continuous across most of the valve face, however, they become interrupted near the poles by a small hyaline region positioned close to the ventral margin (Figs. 17–22). Areolae are small, circular, closely aligned, occluded externally by a solid disc-shaped hymen (Figs. 24–26) and opened to the inside of the valve (Figs. 27 and 28). The raphe extends ca. 8–10 μm along the mantle/valve face margin terminating internally



**Table 1.** Characteristics of the waterbodies harboring (1) *Eunotia lewisii*, (2) *E. quadra*, (3) *Frustulia crispula*, (4) *F. inculta*, and (5) *Neidium trainori*.

Location/waterbody	Taxa present	Latitude (N)	Longitude (W)	pH	Cond. ( $\mu\text{S}\cdot\text{cm}^{-1}$ )	Color (Pt-Co units)	TP ( $\mu\text{g}\cdot\text{L}^{-1}$ )	TN ( $\mu\text{g}\cdot\text{L}^{-1}$ )	SD (m)
<b>North Carolina</b>									
Baytree	3	34°40' 59.36"	78°24' 58.77"	4.6	68	23	13	412	0.99
Debbie's Pond	3	34°43' 14.40"	76°57' 56.30"	4.2	130	300	20	1782	0.34
Great Bay	3, 4	34°51' 34.44"	77°03' 07.67"	4.0	93	125	30	465	0.34
Hannah's Pond	3	34°43' 23.14"	76°57' 30.70"	4.2	71	335	28	1398	0.30
Horseshoe Lake	2	34°48' 29.87"	78°39' 05.50"	4.0	49	192	7	554	1.13
Jones Lake	2	34°41' 02.21"	78°35' 50.51"	4.0	71	117	7	474	1.06
Kasia's Pond	3	34°43' 18.60"	76°57' 38.79"	4.5	82	150	17	866	Bottom
Patsy's Pond	5	34°43' 34.53"	76°57' 35.87"	4.7	72	58	14	498	1.22
Pungo Bay	4	35°42' 40.69"	76°34' 09.91"	4.9	124	540	368	3155	0.02
<b>New Jersey</b>									
Absegami	1, 3	39°37' 35.9"	74°25' 33.7"	4.3	66	47	9	310	1.20
Atsion	1	39°44' 23.39"	74°43' 52.52"	4.5	47	251	14	790	0.66
Batsto	1	39°38' 48.55"	74°39' 11.69"	5.8	47	188	14	720	0.66
Blue Hole	3	39°37'	74°53'	4.7	34	131	9	420	Bottom
Chatsworth Lake	1	39°48' 54.91"	74°32' 45.28"	4.2	49	239	33	700	0.40
Egg Harbor	1	39°33' 29.15"	74°36' 29.38"	4.2	60	102	8	430	1.35
Fred's	1	39°23' 39.29"	74°31' 47.99"	5.1	64	47	5	510	Bottom
Harrisville	1	39°39' 53.14"	74°31' 27.21"	4.4	40	63	11	302	0.99
Oswego	1	39°44' 8.64"	74°29' 10.44"	4.3	41	109	10	411	0.54
Pilgrim	1	39°37' 37.23"	74 26' 42.05"	4.5	28	64	12	220	1.00

**Note:** The ponds listed as Debbie's, Kasia's, and Hannah's are unofficial names for three unnamed waterbodies in the Croatan National Forest. Cond, conductivity; TP, total phosphorus; TN, total nitrogen; SD, Secchi disk depth.

with a helictoglossa at the apex (Figs. 27 and 28). Externally, the distal raphe fissure bends sharply at 90° up onto the valve face at the apex, and terminates midway along the valve as a small circular pore (Figs. 17–22 and 23–26). The lower margin of the mantle encircling the valve is thickened (Figs. 27 and 28). Each valve has a single well developed rimoportula present on the mantle, parallel with the apical axis and situated slightly closer to the dorsal margin (Figs. 27 and 28). The cingulum consists of 3–5 open bands each lined with short rows of areolae on the pars exterior. Valves ranged in size from 131–178  $\mu\text{m}$  long and 6–7  $\mu\text{m}$  wide with a striae density of 11–16/10  $\mu\text{m}$ .

**HOLOTYPE:** here designated as the circled specimen on microscope slide marked "H" CAS 222074, deposited at the CAS, San Francisco, CA and illustrated in Figs 14 and 17–18 (close ups).

**ISOTYPES:** Here designated as the circled specimens on microscope slide marked "G" CANA 80501 deposited at CANA, Ottawa, Canada.

**TYPE MATERIAL:** Cleaned sediment deposited at CAS (CAS 623484) and the CANA, Ottawa, Canada (CANA 79763). Collector: P.A. Siver, June 8, 2001.

**TYPE LOCALITY:** Jones Lake, Bladen Lakes State Forest, Elizabethtown, North Carolina, USA, 35°41' 02"N, 76°35' 51"W.

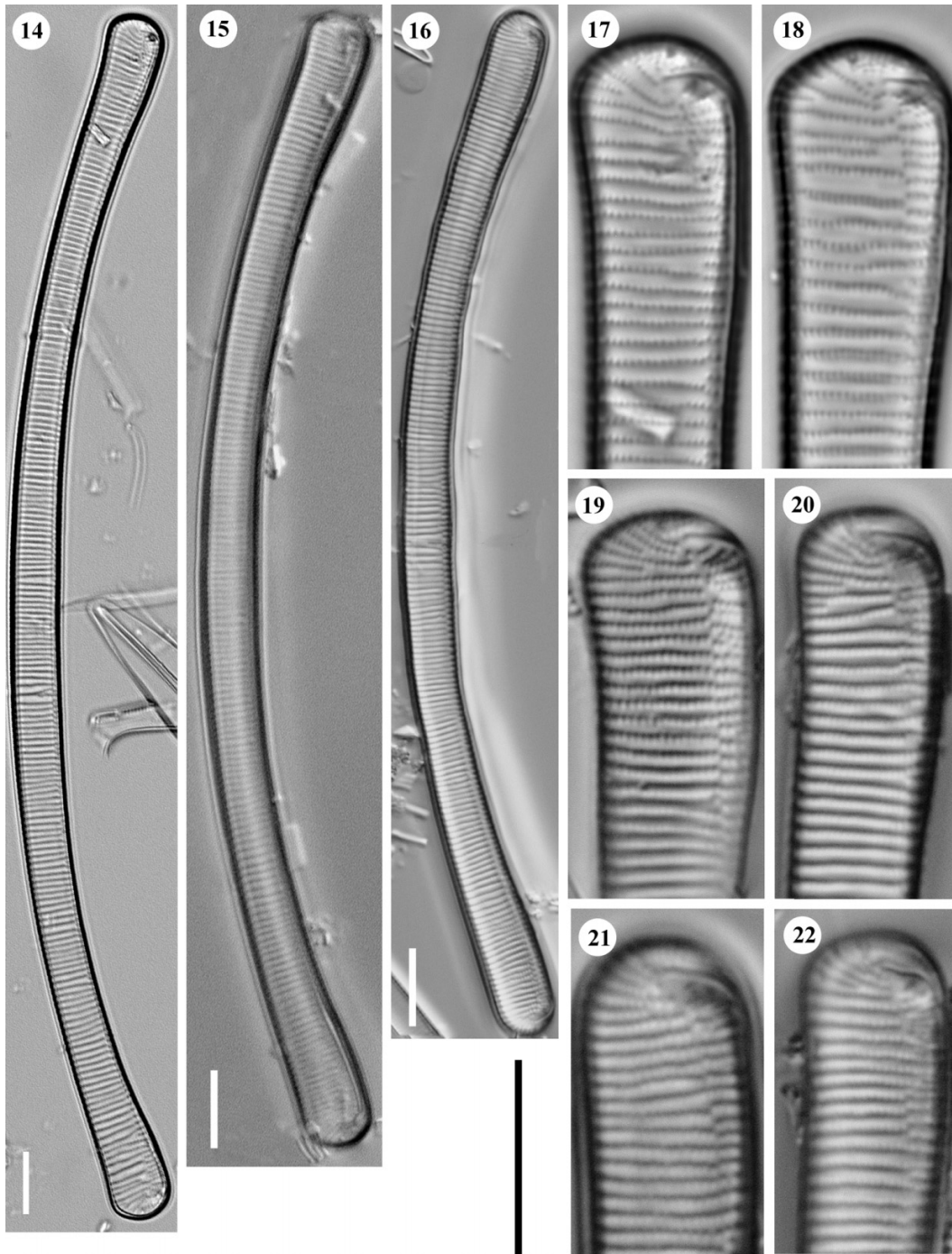
**ETYMOLOGY:** The specific epithet reflects the square-shaped apices.

**DISCUSSION:** In our survey, *Eunotia quadra* could be superficially confused with *Eunotia femoriforme* (Patrick) Hustedt, *Eunotia tauntoniensis* Hustedt, and *Eunotia flexuosa* Brébisson ex Kützing, but the morphology of the valve apices and (or) distal raphe fissures of these latter three species are dis-

tinctly different. The morphology of *E. quadra* is most similar to *E. femoriforme*, but valves of the latter taxon are more slender, generally longer, with slightly capitate apices and distal fissures in the shape of a fish hook (Patrick 1940, Figs. 10–11; Metzeltin and Lange-Bertalot 1998, Plate 14: Figs. 2–4). The distinctive configuration of the distal raphe fissure on *E. femoriforme*, along with the differences in valve shape, readily serves to distinguish this taxon from *E. quadra*. Valves of *E. tauntoniensis* are slightly wider with distinctive triangular-shaped apices and distal raphe fissures that project only a short distance onto the valve face (Simonsen 1987, Plate 42: Figs. 1–6; Patrick and Reimer 1966, Plate 10: Fig. 8; Camburn and Charles 2000, Plate 15: Fig. 12; Gaiser and Johansen 2000, Fig. 38). The distal raphe fissure on *E. flexuosa* bends 180° backwards and runs a good distance down the center of the valve.

Two recently described species by Metzeltin and Lange-Bertalot (2007) that have not been found in North America, *E. karenae* and *E. garciarodriguezii*, bear some resemblance to *E. quadra*. The shape of *E. quadra* valves is similar to one specimen of *E. karenae* illustrated by Metzeltin and Lange-Bertalot (2007, Plate 48: Fig. 1), but differs significantly from the other specimens in having more squared apices that are not reflexed. In addition, the distal raphe fissures on *E. karenae* curve up onto the valve face and terminate near the dorsal margin, whereas those on *E. quadra* bend at a 90° angle and terminate almost precisely midway along the valve face. Valves of *E. garciarodriguezii* (Metzeltin and Lange-Bertalot 2007, Plate 52: Figs. 1–19) are smaller, wider, and also have distal raphe fissures that terminate near the dorsal margin and not midway along the valve face.

**Figs. 14–22.** Light micrographs of *Eunotia quadra*, including a size reduction series (Figs. 14–16) and close-ups depicting the position of the distal raphe fissure, the blunt square-shaped apex and details of the striae. Scale bars = 10  $\mu\text{m}$ ; black bar is for Figs. 17–22.



Besides the type locality, Jones Lake where *Eunotia quadra* is common, this taxon has only been found in another nearby Carolina bay, Horseshoe Lake (Table 1). Both of these localities have a pH near 4.0 and are dilute, moderately humic-stained, and low in total phosphorus concentrations.

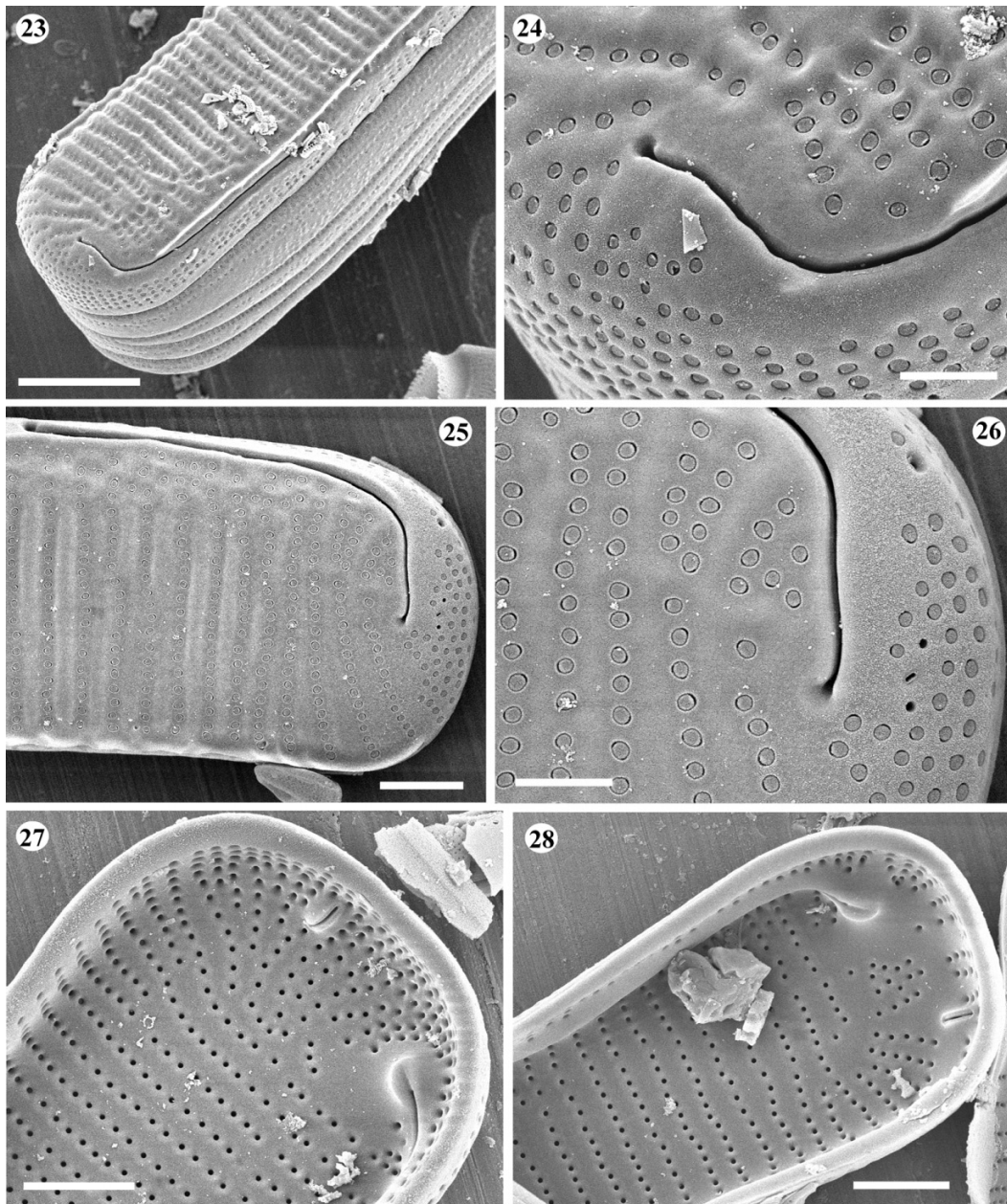
***Frustulia crispula*** Siver, Pelczar, & Hamilton sp. nov. (Figs. 29–50)

DESCRIPTION: *Valvae angustae, lineares ad lineares-lanceolatas,*

*vadosus limbus, rotundi apices, saepe cum sinuatis inaequalibus marginibus* (Figs. 29–33, 39, and 41). *Striae parallelae, leviter convergentes ad extremis, continuae circum apices* (Figs. 47, 48, and 50). *Striae 3–4  $\mu\text{m}$  longitudo circum apicem. Area axialis angusta, linearis, plus minusve immutata in centro valvae* (Fig. 42). *Crassae internae cylindricae costae parallelae raphem, in centro exigua octofigura forma; ad apicem costae circumdant helictoglossam* (Figs. 43 and 49). *Costae raphis complanant ad apicem, expansae secus helictoglossas, plus minusve sagittatae ul-*



**Figs. 23–28.** Scanning electron micrographs of *Eunotia quadra*. Note the “L”-shaped raphe (Figs. 23–26), the marginal ridges (Figs. 23 and 25), the external areolae coverings (Figs. 25 and 26) and the structure of the rimoportula and helictoglossa (Figs. 27 and 28). Scale bars = 1  $\mu\text{m}$  (Figs. 24 and 26); 2  $\mu\text{m}$  (Figs. 25, 27, and 28); and 5  $\mu\text{m}$  (Fig. 23).



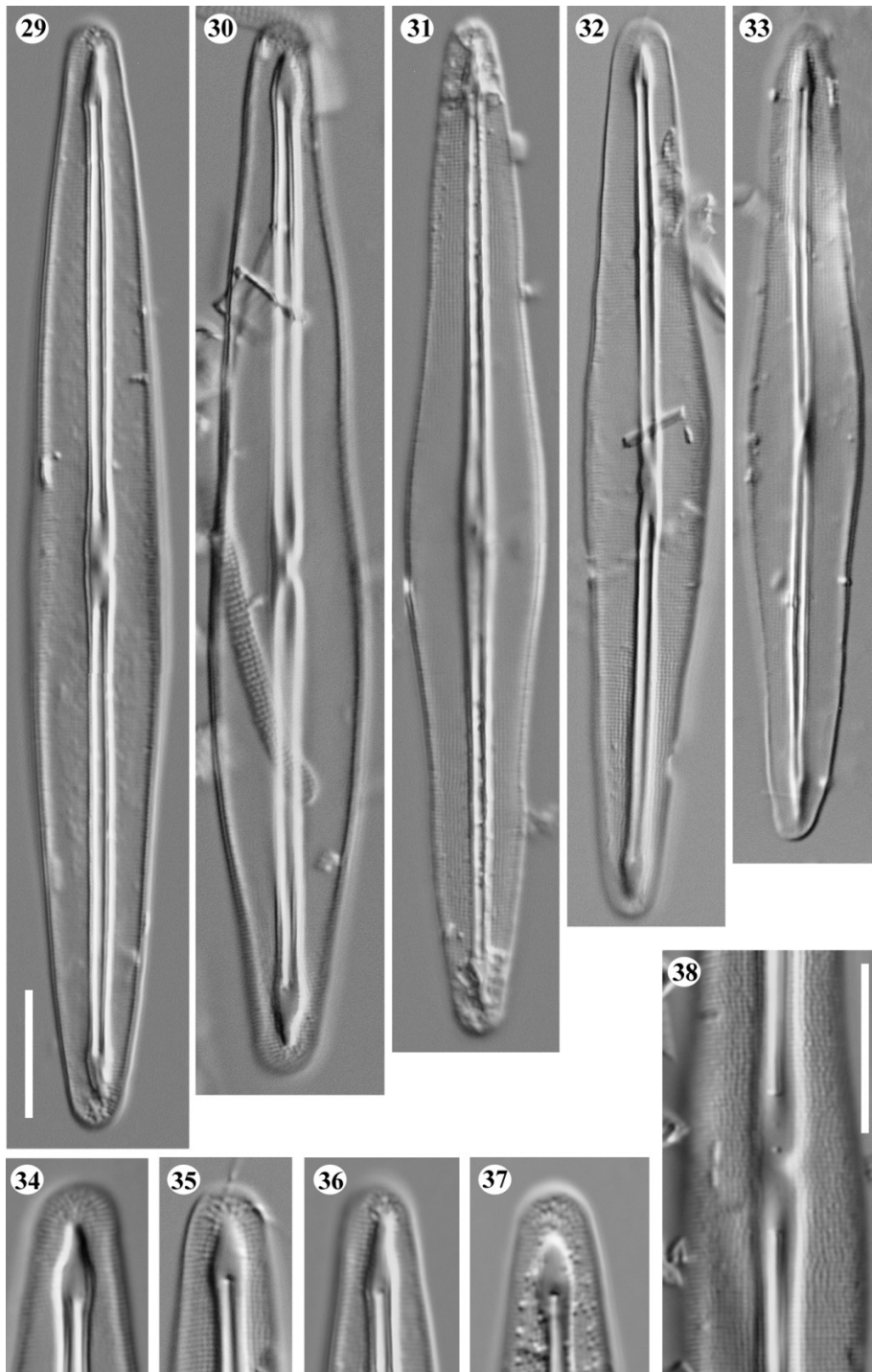
*tra* (Figs. 46–48 and 50). *Helictoglossa lingua, angusta et linearis*. Raphe recta, filiformis cum reflexis proximalibus T-formibus fissuris (Figs. 40–42). Proximales raphis fissurae cum 4.8–6.5  $\mu\text{m}$  separatie (Fig. 42); distales fissurae terminant < 6.5  $\mu\text{m}$  ex apice (Fig. 40). Areolae parvae, circulares ad rimas-similes poros in externa pagina (Figs. 40–42). Interne, uterque areola larga, circularis et tecta cum elevato hymenio (Figs. 44–46, 48, and 50). Four to six cingula taenia per frustulum; saepe affixae etiam post feroces detersas (Figs. 43–44 and 48–49). Cingula taeniae apertae, forcepiformes (Fig. 49), expansae secus valvam formare inclusum cylindricum canalem (Figs. 43–44). Singula serie pororum destituentium tegentium adest in externa pagina cingulae taeniae. Interna cingula taenia

*pagina in latere canali juxta membranam cum singula serie angustae, elongatae aveolae cum hymeniis* (Fig. 44). Valvae 58–85  $\mu\text{m}$  longitudo, 9–11  $\mu\text{m}$  latitudo, striae 34–37/10  $\mu\text{m}$ .

Valves are narrow, linear to linear-lanceolate, often with wavy and uneven margins, shallow mantles and rounded apices (Figs. 29–33, 39, and 41). Striae are parallel over most of the valve surface, becoming slightly convergent at the ends and continuing around the apices (Figs. 47–48 and 50). The striae can be 3–4  $\mu\text{m}$  in length around each apex. The axial area is narrow, linear, and is essentially unaltered in the center of the valve (Fig. 42). Internally, a pair of thick, cylindrical ribs aligns the raphe, fusing in the center to form a slight figure-of-eight design and completely sur-



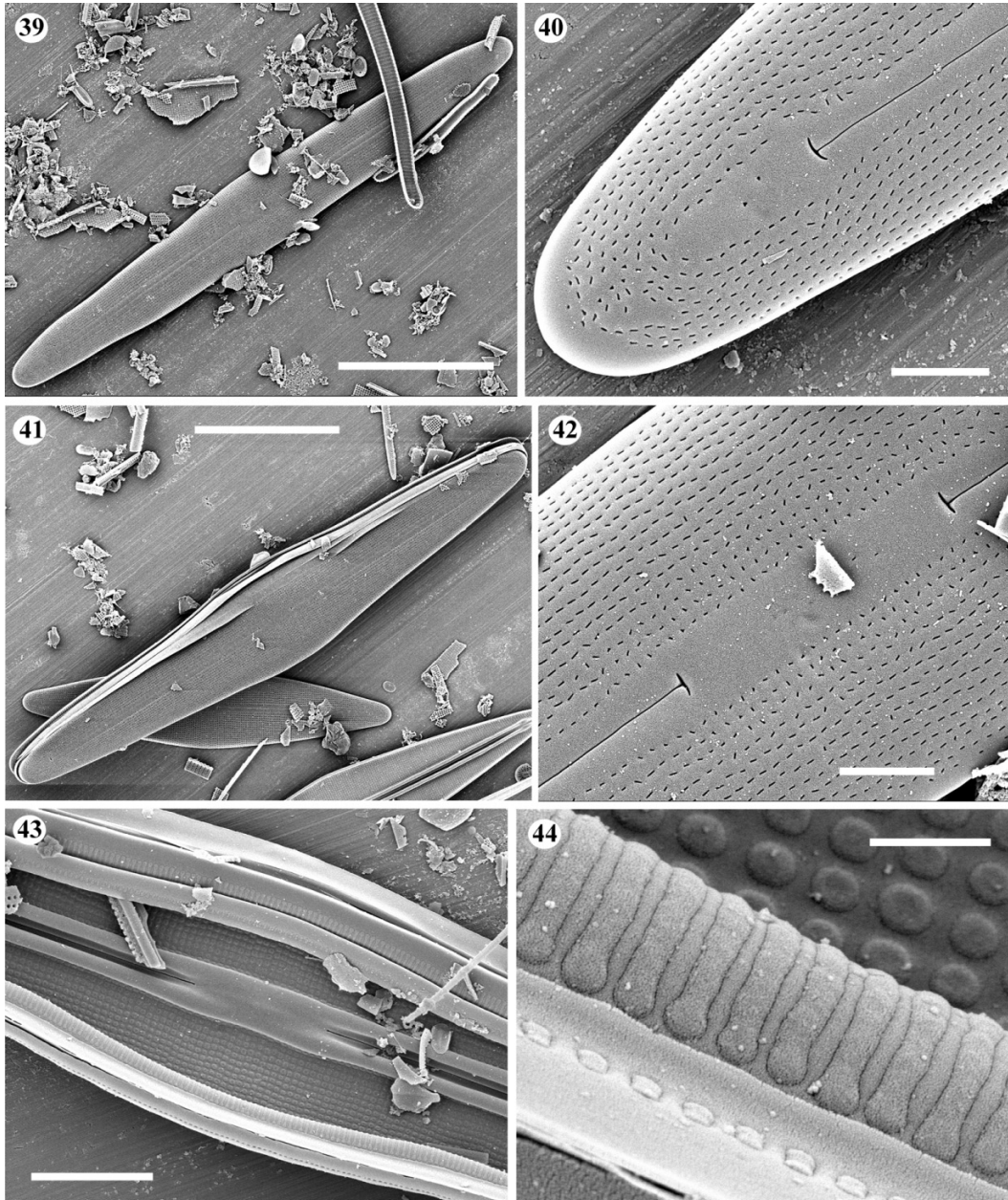
**Figs. 29–38.** Light micrographs of *Frustulia crispula*, including a size reduction series (Figs. 29–33) and close-ups depicting the apex (Figs. 34–37) and uneven central nodule (Fig. 38). Note the uneven, wavy margin, the extended helictoglossa and the short striae surrounding the apex. Scale bars = 10  $\mu\text{m}$ . The top and bottom scale bars are for Figs. 29–33 and 34–38, respectively.



rounding the helictoglossae at the distal ends (Figs. 43 and 49). Typically, the raphe ribs become slightly flattened and expanded along the sides of the helictoglossae and can extend past this latter structure forming an arrowhead shape (Figs. 46–48 and 50). The helictoglossae are long, narrow and linear. The raphe is straight, filiform with slightly reflexed T-shaped fissures (Figs. 40–42). The proximal raphe fissures are widely separated, ranging from 4.8–6.5  $\mu\text{m}$

(Fig. 42) and the distal fissures can terminate up to 6.5  $\mu\text{m}$  from the apex (Fig. 40). The areolae open externally as small circular to slit-like pores, the latter being aligned with the apical axis (Figs. 40–42). Internally, the areolae are much larger, circular and covered with a slightly raised and perforated hymen (Figs. 44–46, 48, and 50). Four to six girdle bands can be found per frustule and despite aggressive cleaning they can often be found still attached to valves

**Figs. 39–44.** Scanning electron micrographs of *Frustulia crispula*. Note the elongated and uneven nature of the valve margin (Figs. 39 and 41), the extensive distance beyond the distal raphe fissure (Fig. 40), the reflexed and T-shaped external raphe fissures (Figs. 40 and 42) and the girdle bands bearing enclosed canals (Figs. 43 and 44). Scale bars = 500 nm (Fig. 44); 2  $\mu\text{m}$  (Figs. 40 and 42); 5  $\mu\text{m}$  (Fig. 43); and 20  $\mu\text{m}$  (Figs. 39 and 41).



(Figs. 43, 44, 48, and 49). The girdle bands are opened, tweezer-shaped (Fig. 49), and become expanded along the valve to form an enclosed cylindrical-shaped canal (Figs. 43–44). A single row of pores lacking coverings usually aligns the external surface of the girdle band. The internal surface, on the side of the canal aligning the cell membrane, consists of a single row of narrow and elongated areolae each with a hymen covering (Fig. 44). Valves ranged in size from 58–85  $\mu\text{m}$  long, 9–11  $\mu\text{m}$  wide, with a striae density of 34–37/10  $\mu\text{m}$ .

**HOLOTYPE:** Here designated as the circled specimen on microscope slide marked “M” CAS 222075, deposited at the

CAS, San Francisco, California, and illustrated in Figs. 29 and 36 (close up).

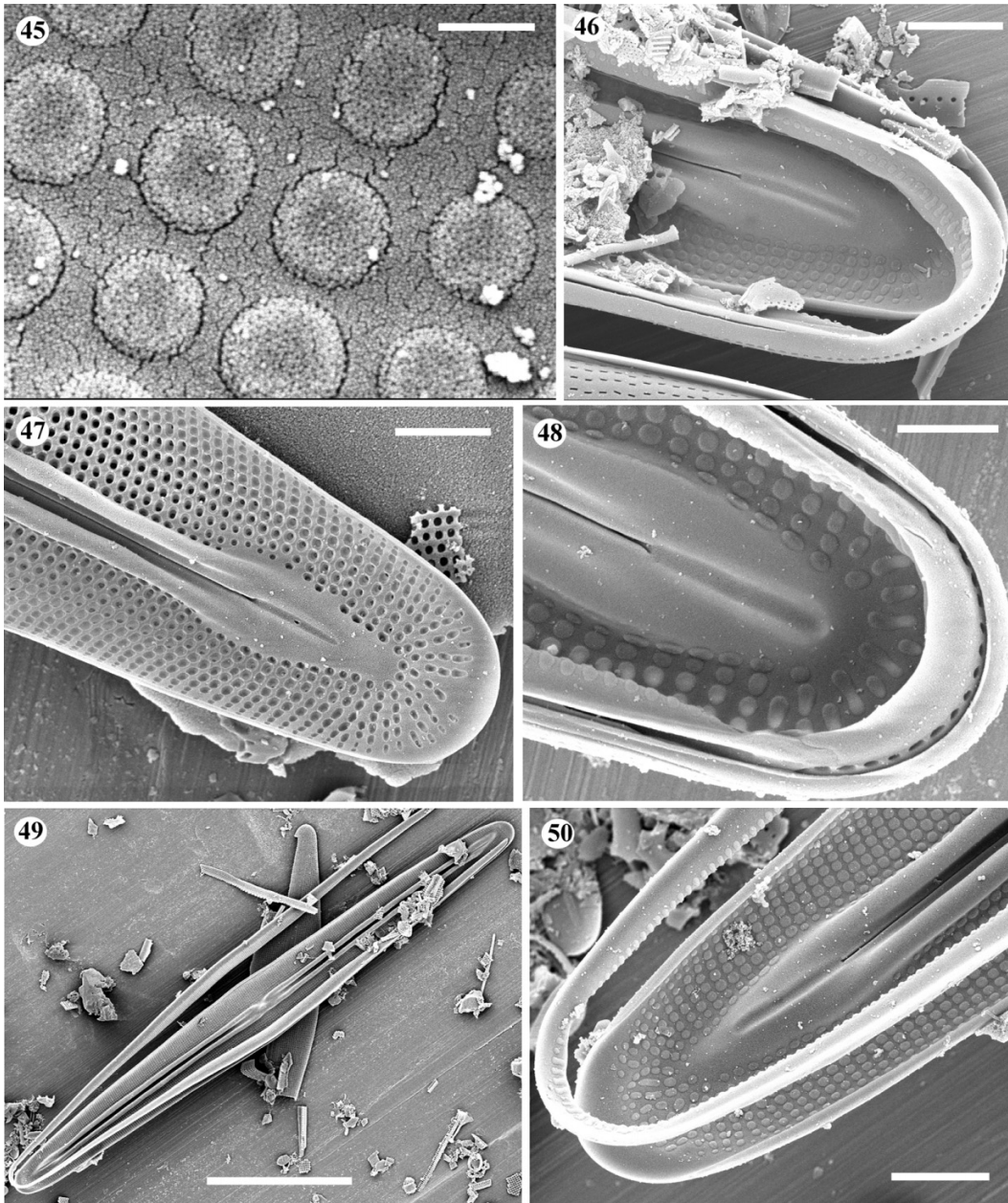
**ISOTYPES:** Here designated as the circled specimen on microscope slide marked “N” CANA 80502 deposited at CANA, Ottawa, Ontario, and the circled specimen on microscope slide marked “O” maintained in P.A. Siver’s personal collection and illustrated in Fig. 31.

**TYPE MATERIAL:** Cleaned sediment deposited at CAS (CAS 623347) and the CANA, Ottawa, Ontario (CANA 79757).  
**Collector:** P.A. Siver, June 5, 2001.

**TYPE LOCALITY:** Small unnamed Carolina bay pond located in



**Figs. 45–50.** Scanning electron micrographs of *Frustulia crispula*. Note the circular areolae coverings along the internal surface (Fig. 45), the elongated and linear helictoglossa encased by a thick, arrowhead-shaped extension of the ribs lining the raphe (Figs. 46–50), the extensive striae surrounding the apex (Figs. 47 and 50), the shallow nature of the valve mantle (Figs. 47 and 49–50), the open girdle bands (Fig. 49) and the chambered nature of the bands (Fig. 50). Scale bars = 200 nm (Fig. 45); 1  $\mu\text{m}$  (Fig. 48); 2  $\mu\text{m}$  (Figs. 46, 47, and 50); and 20  $\mu\text{m}$  (Fig. 49).



the Croatan National Forest, Town of Ocean, North Carolina, 35°43' 14"N, 76°57' 56"W. The pond is situated near Patsy's Pond and is referred to by us using the informal name, Debbie's Pond.

**ETYMOLOGY:** The specific epithet reflects the wavy nature of the valve margin.

**DISCUSSION:** A suite of characters, including the overall shape and size of the valve, shallow mantle, widely spaced proximal raphe fissures, position of the distal end of the raphe, structure of the helictoglossae/raphe rib complex, and girdle

bands clearly serve to separate this taxon from all others within the genus. When we first observed this organism we thought that it may represent an initial cell. However, in all of the localities that harbor this species we found numerous specimens and there were no taxa in these lakes that were consistently smaller and narrower indicating to us that these were clearly not initial cells.

*Frustulia crispula* is most similar to *Frustulia elongatissima* (Manguin) Lange-Bertalot & Metzeltin (in Lange-Bertalot and Jahn 2000). Both of these species have unevenly wavy margins, linear helictoglossae that are posi-

tioned on the valve back from the apex, widely spaced proximal raphe fissures, and can have relatively long striae encircling the apices. However, there is no overlap in the length and width ranges of the two taxa and the striae densities are different (30 in 10  $\mu\text{m}$  for *F. elongatissima*). In addition, the helictoglossae on *F. elongatissima* valves extend past the raphe ribs forming a portae-crayon structure (see Metzeltin and Lange-Bertalot 2007, Plate 130: Figs. 3–5). In the case of *F. crispula*, the raphe ribs completely surround and extend past the helictoglossae and this latter structure does not form a portae-crayon. Based on samples from New Zealand, Foged (1979, Plate 18: Fig. 5) illustrated *F. rhomboides* var. *elongatissima* as a lanceolate valve without undulations and with a distinct portae-crayon, features that do not match *F. crispula*. The only published SEM of *F. elongatissima* (Vyverman 1991, Plate 134: Fig. B) is not similar to *F. crispula* and may not even be representative of *F. elongatissima* sensu stricto.

Like *F. crispula*, specimens of *Frustulia amphipleuroides* (Grunow) Cleve-Euler can have widely spaced proximal raphe fissures and long helictoglossae (Lange-Bertalot 2001, Plate 133: Figs. 1–4), but the latter taxon differs in valve shape and the helictoglossa is associated with a portae-crayon. Several other specimens illustrated in the literature have characteristics similar to *F. crispula*. A small SEM image of a specimen from a peat deposit in Florida (Metzeltin and Lange-Bertalot 2007, Plate 131: Fig. 7), apparently inadvertently assigned to *Frustulia pseudomagaliesmontana* Camburn & Charles by these authors, has a very similar shape and widely spaced proximal raphe fissures, but other features cannot be determined from the image. Another specimen illustrated by Metzeltin and Lange-Bertalot (1998, Plate 116: Fig. 18) as belonging to *F. undosa* has widely spaced proximal raphe fissures, an elongated helictoglossae, and a valve shape similar to *F. crispula*. However, the other 11 specimens illustrated for *F. undosa* are considerably smaller and similar to *F. crassinervia* and we question whether the long and linear specimen belongs with the former species. Interestingly, it is likely that *F. undosa* can have girdle bands similar to those of *F. crispula*. Lastly, an unknown *Frustulia* presented in Metzeltin and Lange-Bertalot (2007, Plate 134: Fig. 1) bears some resemblance to *F. crispula*.

It appears that girdle bands with an enclosed longitudinal canal similar to what we have documented for *F. crispula* are common among *Frustulia* species. We have observed these structures on *F. saxonica*, *F. pseudomagaliesmontana*, and *F. inculta* (see below). In addition, these girdle bands have been illustrated with SEM for several *Frustulia* taxa from Madagascar (Metzeltin and Lange-Bertalot 2002), and we suspect that published images of specimens with LM that bear distinct halos internal to the valve margin also possess these structures. For example, the illustrations of *F. aff. pararhomboides* (Metzeltin and Lange-Bertalot 1998, Plate 116: Figs. 1 and 3) and *F. cf. undosa* (Metzeltin and Lange-Bertalot 2007, Plate 134: Fig. 3) appear to contain canal-bearing girdle bands. Whether the girdle bands with canals serve any function other than holding the valves together is unclear, but we suspect that given the shallow nature of the mantle the canals may be involved in movement of materials between the cell and its environment. Perhaps the girdle band canals have a similar function as the valve canals found in genera

such as *Neidium*. We also know that despite aggressive cleaning procedures girdle bands on *F. crispula* often remain attached to valves.

We have observed populations of *F. crispula* in five Carolina bays within the Croatan National Forest and Bladen Lakes State Forest and two waterbodies in the Pinelands of southern New Jersey (Table 1). The waterbodies are all acidic, poorly buffered, low in dissolved salts concentrations and humic stained with low light penetration.

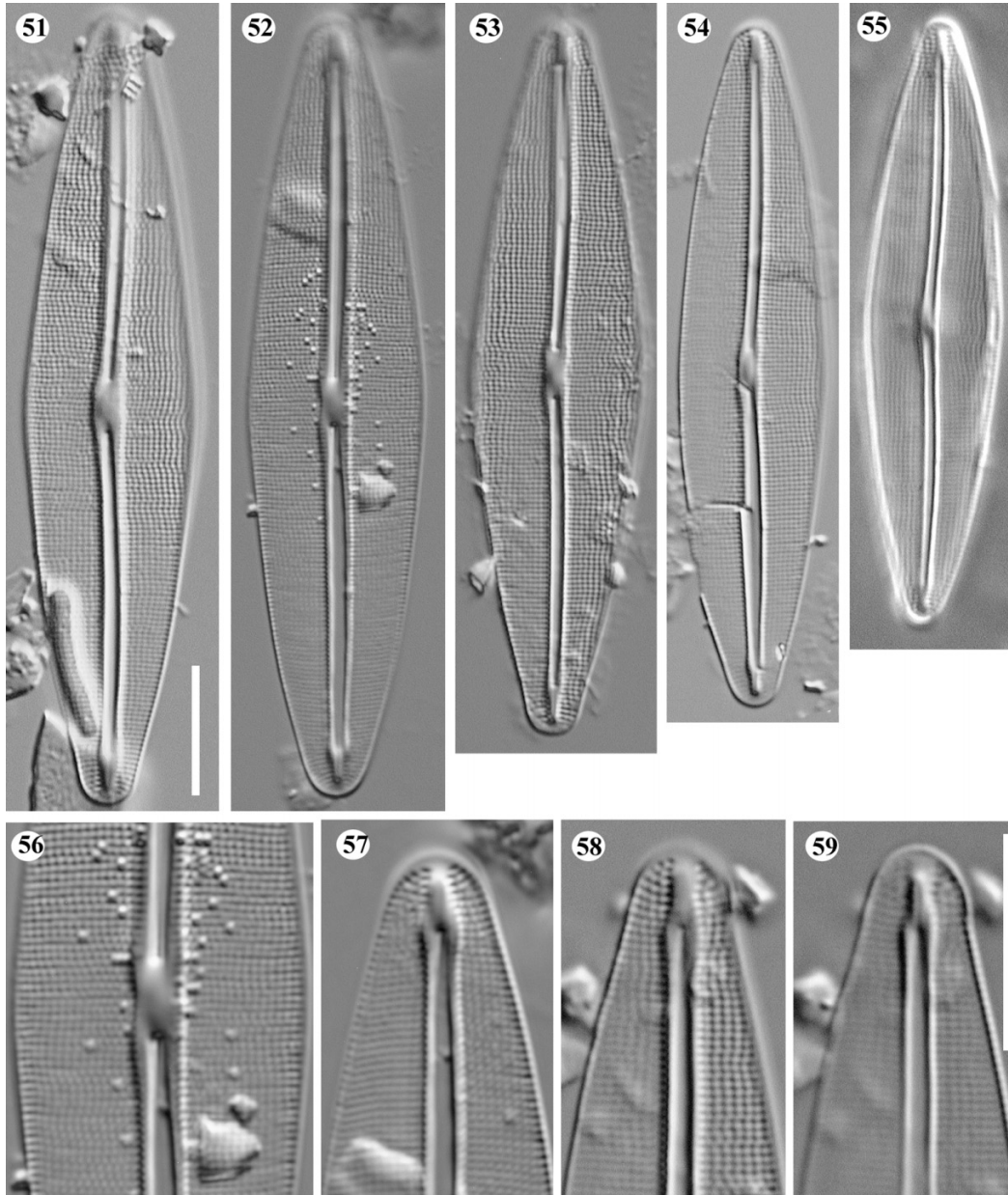
***Frustulia inculta*** Siver, Pelczar, & Hamilton sp. nov.  
(Figs. 51–65)

DESCRIPTION: *Valvae ellipticae-lanceolatae, vadusi limbi et late rotundati apices* (Figs. 51–55 and 60). *Striae plus minusve parallelae, absentes ad polos. Areolae non parallelae inter strias, formantes fractiflexae apicales series* (Figs. 51–59). *Axialis area et costae adiacent raphem, arcuatam vel curvam ex centrali nodula ad apicem* (Figs. 51–55). *Costae raphis inaequaliter connatae in medio; centralis nodulus non concinnus* (Figs. 56 and 62). *Convexus latus axialis regionis plus minusve rectum et minus tumidum; octofiguratus non adest. Regio inter fissuras proximalis raphis incrassata super interna fronde* (Figs. 61 and 62). *Externa pagina, centralis area non expansa. Helictoglossae linguae, lineares et connatae basi cum raphibus costis formare portas-crayon approximatas ad apices* (Figs. 57–59). *Raphe arcuata, filiformis cum T-formis proximalibus et distalibus fissuris* (Figs. 61 and 64). *Externae paginae areolae circulares pori vel elongatae rimae; rimae parallelae cum apicali axe* (Figs. 61 and 63–64). *Interne, areolae grandes, circulares, cum elevatis hymeniis* (Fig. 61). *Four to six cingula taeniae per frustum. Cingula taeniae apertae, forcepiformes et expansae secus valvam formare inclusum cylindricum canalim* (Figs. 62–65). *Cingula taenia, in parte exteriori, cum unae vel duae seriebus inoclularum areolarum* (Figs. 63–64). *Interna cingula taenia pagina in late canaliz parallela cellulam membranam cum singulari serie angustarum, elongatarum areolarum cum hymeniis* (Fig. 65). *Valvae 45–83  $\mu\text{m}$  longitudo, 10–18  $\mu\text{m}$  latitudo, striae 28–30/10  $\mu\text{m}$ .*

Valves are elliptic-lanceolate with shallow mantles and broadly rounded apices (Figs. 51–55 and 60). Striae are parallel over most of the valve face and absent at the poles. The lack of striae around the apices is readily observed with LM (Figs. 57–59). The areolae are not aligned between neighboring striae, forming zig-zagged rows along the apical axis (Figs. 51–59). The axial area and ribs aligning the raphe are bowed or curved between the central nodule and the ends of the valve (Figs. 51–55). The raphe ribs are unevenly fused in the center of the valve forming an asymmetric central nodule (Figs. 56 and 62). The side of the central nodule aligned with the convex side of the axial region is straighter and less swollen than the concave side. As a result, a distinct figure-of-eight design is not formed. The region between the proximal raphe fissures is thickened internally (Figs. 61–62). On the external surface, the central area is not expanded. The helictoglossae are long, linear, and fused at the base with the raphe ribs to form a portae-crayon structure that terminates close to the ends of the valve (Figs. 57–59). The raphe is bowed, filiform, with T-shaped proximal and distal fissures (Figs. 61 and 64). The areolae open externally as circular pores or elongated slits, the latter of which



**Figs. 51–59.** Light micrographs of *Frustulia inculta*, including a size reduction series (Figs. 51–55) and close-ups depicting the asymmetrical central nodule (Fig. 56) and the apex (Figs. 57–59). Note the curved raphe ribs, the untidy alignment of the areolae and the lack of areolae around the apex. Scale bars = 10  $\mu$ m. The smaller bar is for Figs. 51–55 and the larger one for Figs. 56–59.



are aligned with the apical axis (Figs. 61, 63, and 64). Internally, the areolae are larger, circular and covered with a slightly raised and perforated hymen cover (Fig. 61). Four to six girdle bands can be found per frustule. The girdle bands are open, tweezer-shaped, and become expanded along the valve to form an enclosed cylindrical-shaped canal (Figs. 62–65). One or two rows of unoccluded areolae align the pars exterior of the girdle band (Figs. 63 and 64). The internal surface, on the side of the canal aligning the cell membrane, consists of a single row of narrow and elongated areolae each with a hymen covering (Fig. 65). Valves range in size from 45–83  $\mu$ m long, 10–18  $\mu$ m wide, and have a striae density of 28–30/10  $\mu$ m.

**HOLOTYPE:** Here designated as the circled specimen on micro-

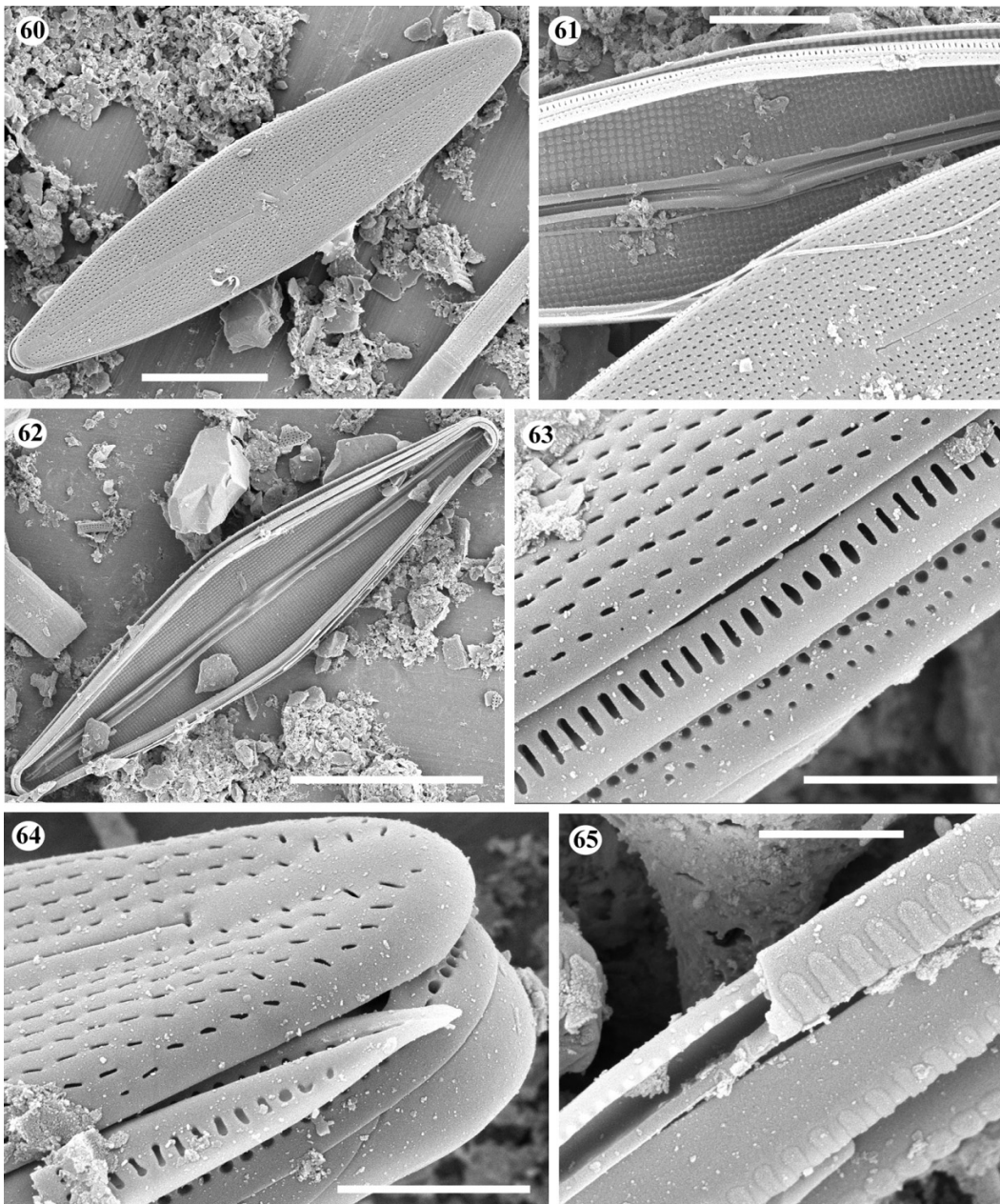
scope slide marked “R” CAS 222076, deposited at the CAS, San Francisco, California, and illustrated in Fig. 53.

**ISOTYPES:** Here designated as the circled specimen on microscope slide marked “S” CANA 80503 deposited at CANA, Ottawa, Ontario, and illustrated in Figs. 52, 56, and 57 (close ups).

**TYPE MATERIAL:** Cleaned sediment deposited at CAS (CAS 623194) and the CANA, Ottawa, Ontario (CANA 79769). Collector: P.A. Siver, June 5, 2001.

**TYPE LOCALITY:** Pungo Lake, a larger Carolina bay water-body located within the Pocosin National Wildlife Refuge, Town of Creswell, North Carolina, 35°42' 41"N, 76°34'10"W.

**Figs. 60–65.** Scanning electron micrographs of *Frustrulia inculta*. Note the overall valve shape (Figs. 60 and 62), the asymmetrical central nodule (Figs. 61 and 62), the shallow mantle (Fig. 63 and 64) and the nature of the girdle bands (Figs. 62–65), including the enclosed canal (Fig. 65). Scale bars = 1  $\mu\text{m}$  (Fig. 65); 2  $\mu\text{m}$  (Figs. 63–64); 5  $\mu\text{m}$  (Fig. 61); 10  $\mu\text{m}$  (Fig. 60); and 20  $\mu\text{m}$  (Fig. 62).



**ETYMOLOGY:** The specific epithet reflects the untidy nature of the areolae.

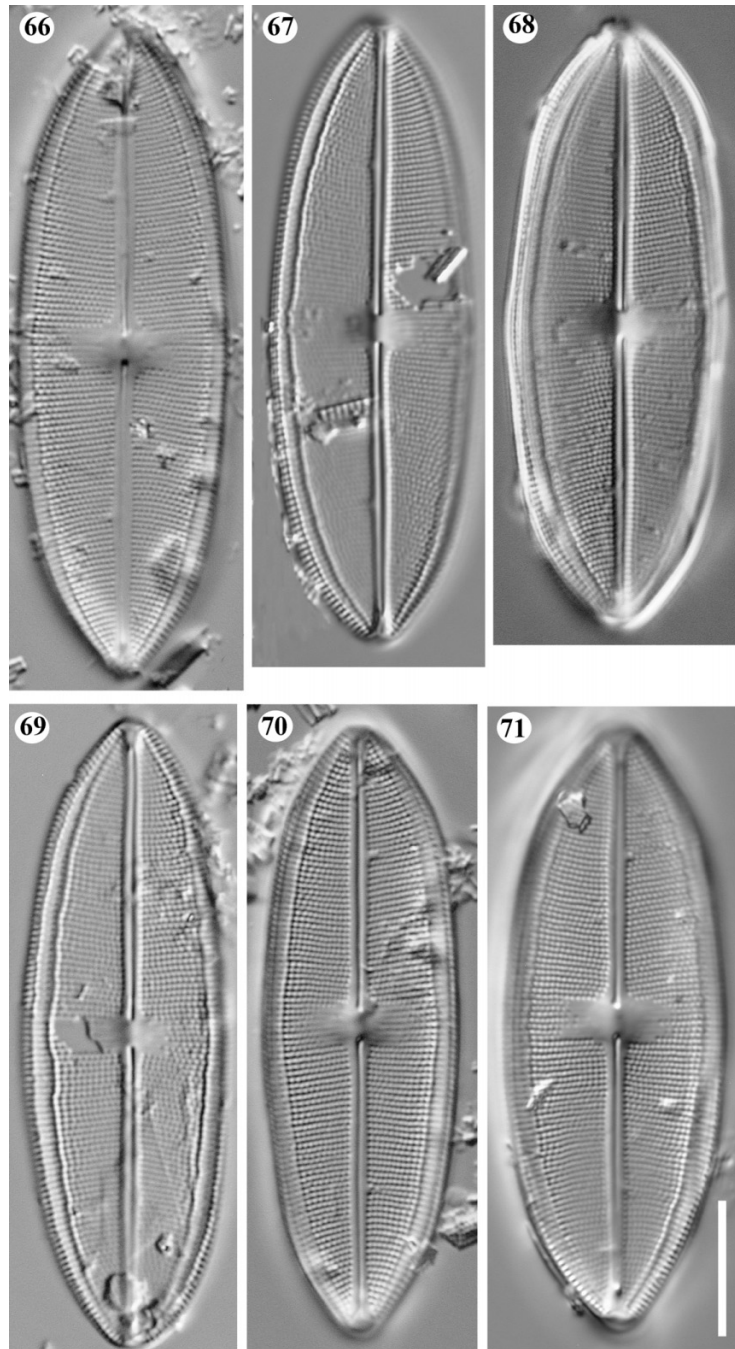
**DISCUSSION:** The combination of valve morphometrics, untidy alignment of the areolae along the apical axis, bowed axial region, asymmetric central nodule, lack of striae around the apices, coupled with the long helictoglossae, serve to distinguish this species from others within the genus. We were unable to find any records of similar specimens in the literature with the possible exception of morphotype I of *Frustrulia erifuga* Lange-Bertalot & Krammer noted by Lange-Bertalot and Metzeltin (1996, Plate 39: Figs. 1 and 2). Lange-Bertalot (2001) identified two morphotypes for *F. erifuga*. Morphotype I is broader, more elliptic-lanceolate, and lacking areolae

around the apices. Morphotype II is more linear-lanceolate with somewhat protracted ends and possesses areolae around the apices. Our taxon resembles morphotype I in some respects, but not morphotype II. The areolae of morphotype I and *F. inculta* are similar in being unevenly aligned along the apical axis. The curved nature of the axial region and raphe ribs, the asymmetric central nodule and the portae-crayon are also similar. However, our specimens are significantly smaller and have a higher striae density than *F. erifuga* morphotype I. Further, they possess canal-bearing girdle bands, similar to those noted above for *F. crispula* but not for *F. erifuga*.

*Frustrulia inculta* has been observed in two of the larger Carolina bays, Pungo and Great, both highly acidic, poorly



**Figs. 66–71.** Light micrographs of *Neidium trainori* depicting the broad oval valve shape, central area, large marginal canal, and straight proximal raphe ends. Scale bar = 10  $\mu\text{m}$ .



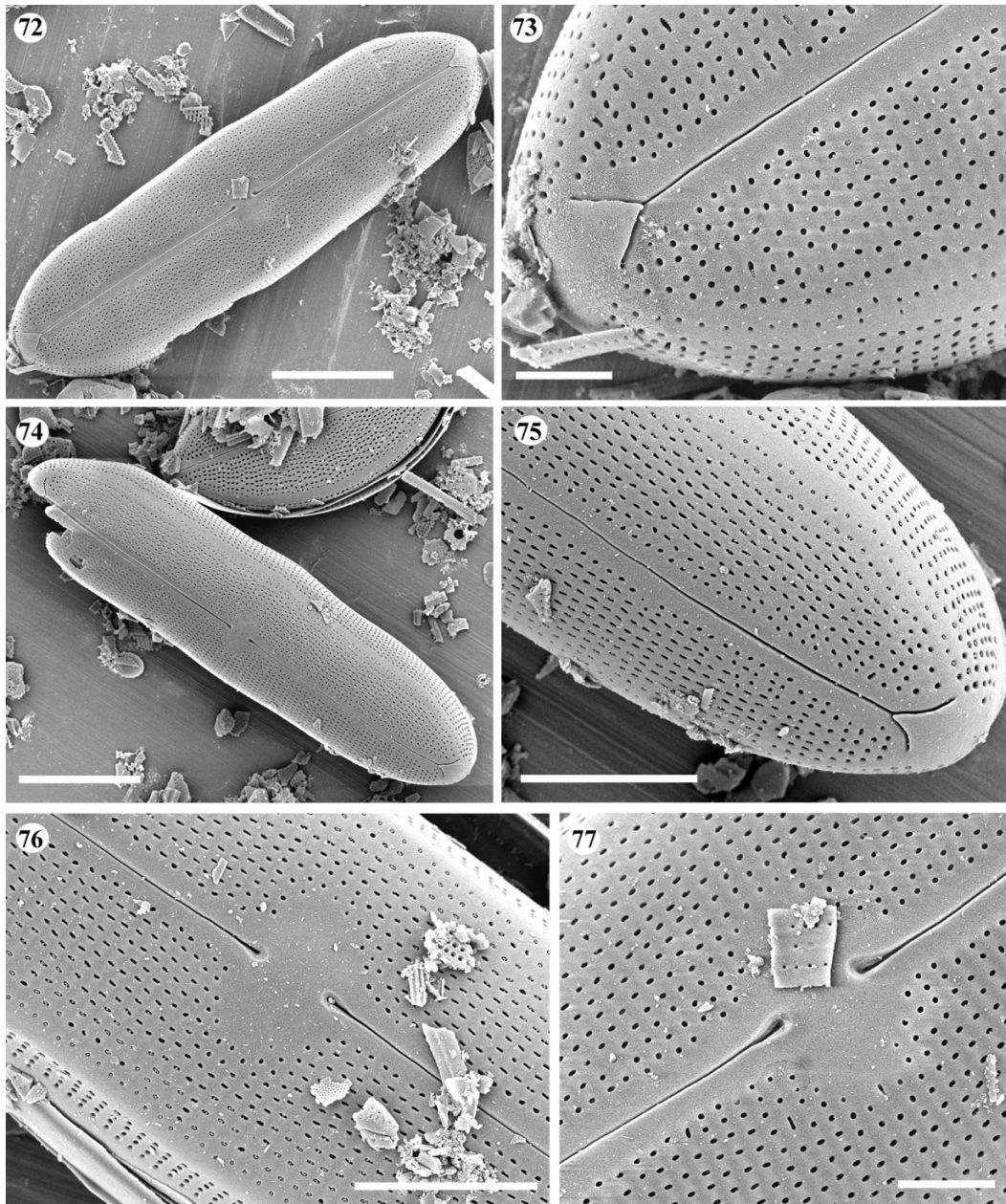
buffered and humic stained waterbodies (Table 1). The nutrient levels in Pungo were extremely high most likely reflecting the large numbers of waterfowl on the lake at the time of collection.

***Neidium trainori*** Siver & Hamilton sp. nov. (Figs. 66–83)

**DESCRIPTION:** *Valvae latae, lineares ad lineares-ellipticas cum obtusis rotundis apicibus et profundis limbis* (Figs. 66–71, 72, and 74). *Unus grandis, latus longitudinalis canaliz secus uterque marginem* (Figs. 80–82). *Striae uniseriatae deorsum ad limbum basim, leviter radiatae super frondem*. *Area axiali angusta, linearis, expansa ad ellipticam vel circula-*

*centralem aream* (Figs. 66–71 and 76–77). *Interna axiali regio incrassata*. *Raphe filiformis, vecta; distales et proximales fissurae grandes, lacrimiformes pori* (Figs. 76–78). *Proximales raphis fissurae rectae, non recurvae* (Figs. 76 and 77). *Distales raphis fissurae parvae, V-formis lacinia ad apicem in fronde* (Figs. 72–75). *Aliquae valvae deficiunt laciniam* (Fig. 78). *Interna raphe super cristam crassam; distales extrema terminant prop distinctis helictoglossis*. *Areolae locellatae in valvae pariete; parvae exterior circulares ad rimas-similes orificia* (Figs. 72–79), *interna areola aperiens grandis, circularis ad quadratiformem, tecta ab plano hymenio* (Figs. 80–83). *Externe, areolae poterant ob-*

**Figs. 72–77.** Scanning electron micrographs of the external surface of *Neidium trainori*. Note the wavy triundulate form of the valve margin (Figs. 72 and 74), the deep mantle (Fig. 75), the central area and straight proximal raphe fissures with large tear-shaped pores (Figs. 76 and 77) and small V-shaped lacinia on the valve face (Figs. 73 and 75). Scale bars = 2  $\mu\text{m}$  (Figs. 73 and 77); 5  $\mu\text{m}$  (Figs. 75 and 76); and 10  $\mu\text{m}$  (Figs. 72 and 74).



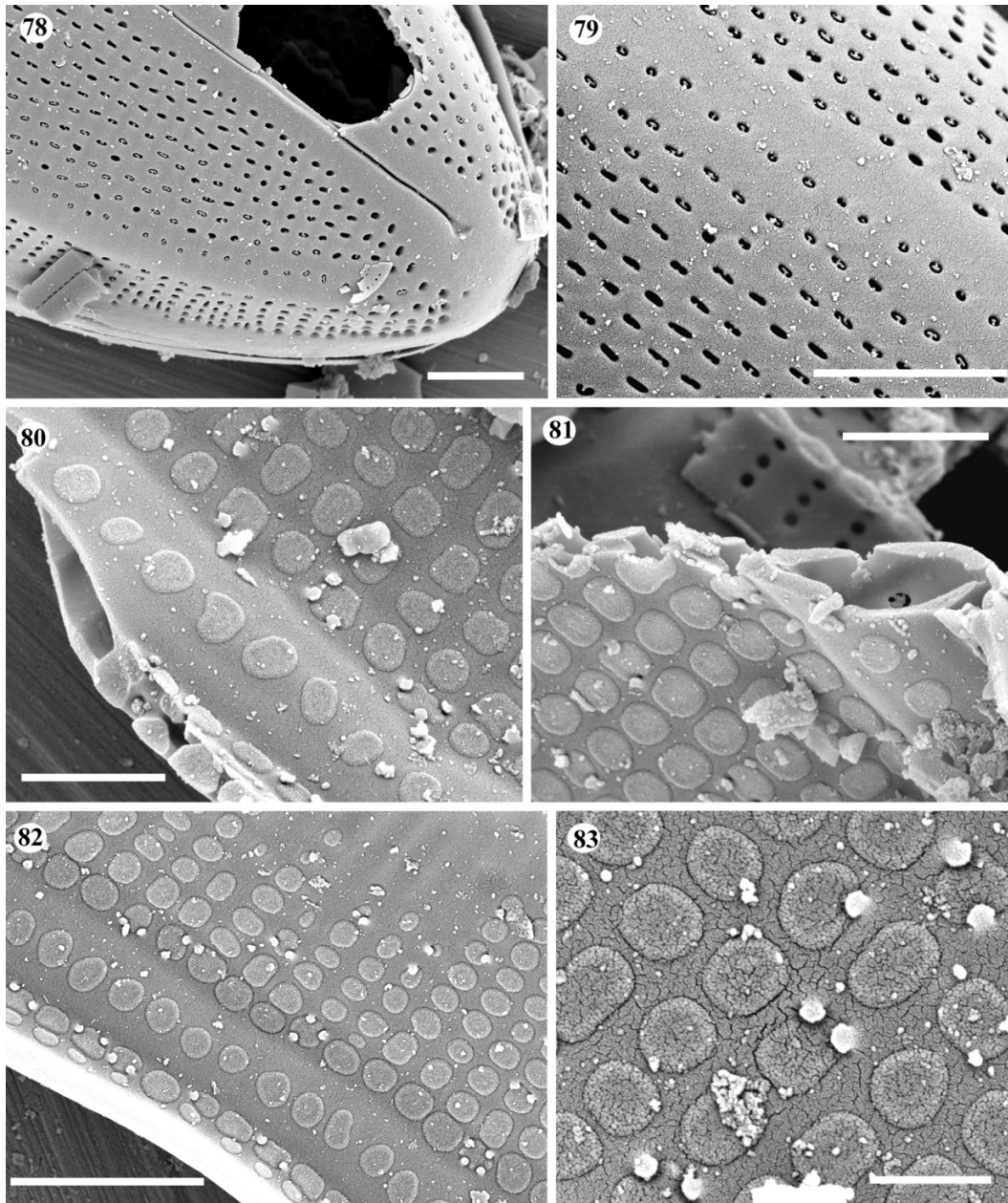
*tegere cum una vel duo digitiformibus projecturis* (Fig. 79). *Areolae juxta canales plus dispositae, leviter propagula facientes sinuatas longitudinales lineas* (Figs. 73–75). *Singula serie areolae parallelae vertex et fundus canaliz* (Figs. 80–82). *Externa et interna orificia canaliz areolae similiae ad frondem areolas* (Figs. 81). *Voigt vitia adunt. Renilimbi adunt, communes circum areolas adiacentes raphi vel structuris canaliz* (Figs. 82 and 83). *Valvae 40–50  $\mu\text{m}$  longitudo, 11–15.5  $\mu\text{m}$  latitudo, striae 23–27/10  $\mu\text{m}$ .*

Valves are broadly linear to linear-elliptical with bluntly rounded apices and deep mantles (Figs. 66–71, 72, and 74). A large, broad longitudinal canal is found along each margin (Figs. 80–82). The striae are uniseriate, slightly radiate over

the valve surface and extend onto and to the base of the mantle. The axial area is narrow, linear and opens into an elliptical to circular central area (Figs. 66–71 and 76–77). Internally, the axial region is thickened. The raphe is fili-form, straight with distal and proximal fissures that terminate as large tear drop-shaped pores (Figs. 76–78). The proximal raphe fissures are straight and not recurved (Figs. 76 and 77). The distal raphe fissures end as small, V-shaped lacinia situated at the apex on the valve face (Figs. 72–75). The apices of some valves lacked lacinia (Fig. 78). Internally, the raphe is positioned on a thickened ridge with distal ends that terminate as distinct helictoglossae. The areolae form chambers in the valve wall with small



**Figs. 78–83.** Scanning electron micrographs of *Neidium trainori*. Note the small circular to slit like external openings of the areolae (Figs. 78 and 79), the large circular hymen coverings on the internal surface (Figs. 80–83), the structure of the renilimbi (Fig. 83), and the single large canal along each valve margin (Figs. 80–82). The valve depicted in Fig. 78 lacks a lacinia. Scale bars = 500 nm (Fig. 83); 1  $\mu$ m (Figs. 80–81); and 2  $\mu$ m (Figs. 78, 79, and 82).



exterior openings that range in shape from circular to slit-like (Figs. 72–79) and larger circular to square-shaped interior openings covered by a flat hymen (Figs. 80–83). Externally, each areola can be partially occluded with one or two finger-like projections (Fig. 79). The areolae next to the canals are more widely spaced and slightly offset between adjacent striae forming wavy longitudinal lines (Figs. 73–75). A single row of areolae align the top and bottom of the canal (Figs. 80–82). The external and internal openings of the canal are similar to the others on the valve, but are connected to the canal (Fig. 81). Voigt faults can be observed with either LM or SEM. Renilimbi are often associated with the areolae, especially those situated along the raphe and ca-

nal (Figs. 82 and 83). Valves ranged in size from 40–50  $\mu$ m long, 11–15.5  $\mu$ m wide and have a striae density of 23–27/10  $\mu$ m.

**HOLOTYPE:** here designated as the circled specimen on microscope slide marked “N” CAS 222077, deposited at the CAS, San Francisco, California, and illustrated in Fig. 70.

**ISOTYPES:** Here designated as the circled specimens on microscope slide marked “P” CANA 80504 deposited at CANA, Ottawa, Ontario, and slides marked “O” and “M” maintained in P.A. Siver’s personal collection. Circled specimens on slides “P,” “O,” and “M” are illustrated in Figs. 71, 67, and 68, respectively.

TYPE MATERIAL: Cleaned sediment deposited at CAS (CAS 623382) and the CANA, Ottawa, Ontario, (CANA 79767). Collector: P.A. Siver, 31 May 2001.

TYPE LOCALITY: Patsy's Pond, Croatan National Forest, Town of Ocean, North Carolina, 35°43' 35"N, 76°57' 36"W.

ETYMOLOGY: The specific epithet is in honor of Francis R. Trainor on his 80th birthday.

DISCUSSION: Although the majority of *Neidium* species have recurved proximal raphe fissures, a number of taxa have straight fissures like *N. trainori*. In our survey of diatoms along the east coast of North America the other similar species with straight proximal raphe fissures is *Neidium densestriatum* (Østrup) Krammer. Both *N. densestriatum* and *N. trainori* have similar finger-like occlusions on the exterior surface of the areolae and a single large canal along each margin. Valves of *N. densestriatum* differ in being broadly elliptical-lanceolate with more apiculate apices, shallow mantles and lacinia that extend onto the mantle (Stachura-Suchoples et al. 2004, Figs. 49–64). There are a number of taxa, including *Neidium dubium* (Ehrenberg) Cleve, *Neidium cuneatiformis* Levkov, *Neidium acutum* Levkov & Kristic, and *Neidium binodis* (Ehrenberg) Hustedt, that have straight proximal raphe ends and distal lacinia. All of these species differ from *N. trainori* in valve morphology, especially with respect to the shape of the apices. Two other taxa observed in our survey, *Neidium pseudodensestriatum* Stachura-Suchoples & Kociolek (Stachura-Suchoples et al. 2004) and *Neidium apiculatum* Reimer (Siver et al. 2005), bear a slight resemblance to *N. trainori*, however both of these species have oppositely reflexed proximal raphe fissures and more elliptical-shaped valves with more pointed apices.

To date, *N. trainori* has only been found in the type locality, Patsy's Pond, a small acidic Carolina bay situated very close to the Atlantic Ocean (Table 1).

## Summary

Freshwater lakes and ponds along coastal North Carolina and southern New Jersey are largely shallow, acidic, dilute waterbodies with significantly humic-stained waters. This complement of chemical conditions often yields diatom floras dominated with taxa from the genera *Frustulia* and *Eunotia* and lesser contributions from genera such as *Neidium*. Two of the newly described species, *Eunotia quadra* and *F. inculta*, were each found as common elements in a suite of geographically close waterbodies, but were not widely distributed along the Atlantic Coastal Plain. *Neidium trainori* was even more restricted, only observed from Patsy's Pond, which is situated among a suite of waterbodies also harboring *F. crispula*. Of the five species, only *F. crispula* has been observed in localities from both North Carolina and New Jersey. Lastly, *Eunotia lewisii* was widely distributed among the geographically close Pineland waterbodies of southern New Jersey, but has not been observed in over 70 acidic sites examined further south on the Atlantic Coastal Plain. The fact that *E. lewisii* is also present in Saco Pond, a small acidic locality in the White Mountains of New Hampshire, is of particular interest from a biogeographic point of view since this taxon has not been observed in over 150 additional sites examined by us in New Eng-

land, nor in numerous waterbodies studied as part of the Paleocological Investigation of Recent Lake Acidification (PIRLA) project (Camburn and Charles 2000). All of the newly described species possess a unique complement of characters that readily distinguish them from other taxa. In particular, the distribution of canal-bearing girdle bands within the genus *Frustulia* warrants further investigation. The circumscription of the taxa presented improves our knowledge of the biodiversity of freshwater diatoms in eastern North America.

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